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# RF COAXIAL RESONATOR FOR INVESTIGATING MULTIPACTOR DISCHARGES ON METAL AND DIELECTRIC SURFACES

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## Abstract

Multipactor discharge is a phenomenon in which electrons impact one or more material surfaces in resonance with an alternating electric field. The discharge can occur for a wide range of frequencies, from the MHz range to tens of GHz, and in wide array of geometries if the impacted surface has a secondary electron emission (SEE) yield larger than one. The discharge can take place on a single surface or between two surfaces. A novel coaxial resonator to investigate two-surface multipactor discharges on metal and dielectric surfaces in the gap region under vacuum conditions has been designed and tested. The resonator is ~ 100 mm in length with an outer diameter of ~ 60 mm (internal dimensions). A pulsed RF source delivers up to 30 W average power over a wide frequency range 650-900 MHz to the RF resonator. The incident and reflected RF signals are monitored by calibrated RF diodes. An electron probe provides temporal measurements of the multipacting electron current with respect to the RF power. These experiments were successful in identifying multipacting and allowed us the evaluation of a home made sputtered titanium nitride (TiN) thin layers as a Multipactor suppressor.

## INTRODUCTION

A multipactor discharge is a phenomenon in which electrons impact one or more material surfaces in resonance with an alternating electric field [1]. Two main conditions must be met in order to develop a multipactor discharge between two material surfaces. First, electrons traversing the gap must impact the electrode near the time the E-field reverses the direction. Second, electrons must impact the surface with enough energy to create electron multiplication by secondary emission, i.e.  $\delta(E) \geq 1$ . The discharge is sustained by the population of electrons that remain in phase with the RF electric field. Because the discharge is sustained by secondary electrons, multipactor discharges typically occur under vacuum conditions.

Multipactor discharges are considered detrimental to RF systems in most applications. The discharges can cause vacuum window failure, limit the delivery of RF power, detune resonant cavities, damage high power RF sources, and cause a local pressure rise due to the desorption of surface gases[2]. As mentioned, multipactor (MP) is often an undesirable phenomenon, and avoidance can be critical in the operation of certain systems, it can be avoided in several ways. A general cure against multipacting is to avoid the resonant conditions by either a proper choice of the geometry of the device [3, 4] or by coating the critical areas with a material with a lower secondary yield [5,6]. This way the effect of multipacting

can be significantly reduced, but very often the MP phenomenon cannot be removed.

Titanium nitride (TiN) coating is used as a proven anti-multipacting coating for inter-cavity coupling slots, RF vacuum windows and RF coupling loops. Several experimental investigations have been performed at DESY and LAL-Orsay, aimed at reducing secondary electron emission and multipactor effects by TiN layers generation on dielectric or metal surfaces [7, 8].

We propose here an experiment facility for investigating two-surface multipactor discharges on dielectric and metal surfaces. The compact apparatus consists of a RF coaxial resonator in a high vacuum system (~  $10^{-8}$  mbar). The RF resonator is ~ 100 mm in length with an outer diameter of ~ 60 mm (internal dimensions), powered with a pulsed RF source delivering up to 30W average power. These experiments were successful in identifying multipacting and allowed us the evaluation of a homemade sputtered titanium nitride (TiN) thin layers as a Multipactor suppressor.

## COAXIAL RESONATOR MULTIPACTOR EXPERIMENT

The RF coaxial resonator is ~ 100 mm in length with an outer diameter of ~ 60 mm (internal dimensions). The resonator's dimensions were chosen because of the available laboratory equipment. It is made out of stainless steel whose inner walls plated with copper and equipped with 4 ports: on the top, a small coaxial line penetrates the upper center electrode to provide a direct measure of the multipacting current, the bottom port for the pumping system, and two horizontal ports for RF coupling. Both RF antennas have the same coupling in order to maintain the symmetry of the central electric field. The RF antennas and diagnostics are accessed with vacuum feedthroughs. The flanges are also fabricated from stainless steel. Several pairs of center electrodes have been made from Cu, Al, and Stainless steel (S.S). One electrode sample holder made out of Cu was developed for investigating multipactor discharges on different material surfaces (Alumina ceramic (97.6%  $\text{Al}_2\text{O}_3$ ), TiN coated Alumina). The dielectric samples have the square shape with a 10 mm edge length and 1 mm thickness. The vacuum system allows low pressures of ~  $10^{-8}$  mbar.

A pulsed RF source delivers up to 30 W average power over a wide frequency range 650-900 MHz to the RF resonator. The pulse width and repetition rate used were 50 ms and 4Hz, respectively (20% duty cycle). The RF circuit is straightforward and illustrated in Fig.1.

The power supply is fed into a circulator which is then attached to a dual directional coupler. The forward and reflected RF powers are monitored by calibrated RF diodes (RF detectors). The electron probe is connected to an electronic circuit. A four 15 V batteries in series allow the bias of the electron probe and a current to voltage converter (1mA/V) provides temporal measurements of the multipacting electron current with respect to the RF power.

Data acquisition is controlled by Visual Basic for Applications (VBA). All measured data are recorded and stored in tab delimited format which the signals can be plotted in an Excel © spread sheet.

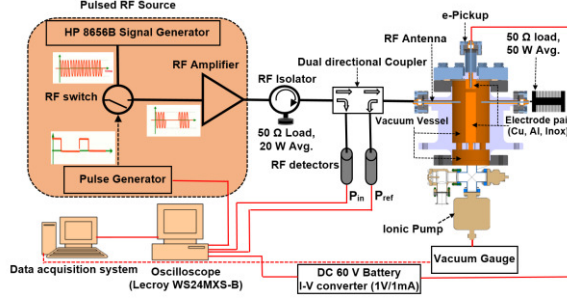


Figure 1: Scheme of the coaxial resonator multipacting test bench.

## EXPERIMENTAL RESULTS

For each measurement the electrodes are prepared for vacuum by abrasively cleaning to a moderately polished finish. They are then vacuum cleaned with alcohol before entering the vacuum vessel. After assembly of a pair of electrodes the upper conflat flange is closed and the resonator is pumped to a base pressure around  $10^{-8}$  mbar through its bottom port. In order to initiate the multipactor discharge, The RF resonator is first tuned to the desired frequency with a vector network analyzer. The RF source is then locked to the high-Q RF resonator. At the multipactor onset, the multipacting current and pressure variation were measured.

### Measurement of RF Resonator Parameters

The S parameters' measurement were carried out with a Vector Network Analyzer (VNA). A good RF matching of the RF resonator was obtained. Main RF resonator parameters are summarized in Table 1.

Table 1: RF Resonator parameters

Resonant frequency	784 MHz
Insertion loss (I.L)	-1.6 dB
Return Loss	-21 dB
Loaded quality factor $Q_L$	500
Coupling coefficient $\beta_c$	0.85

### Two-Surface Multipactor on Metals

Multipactor discharges between two metallic electrodes with a diameter of 20 mm and separated by a gap of width

$d=6\text{mm}$  has been studied and characterized. The resonant condition for two side multipacting in a perpendicular RF electric field is given by:

$$E_N = \frac{V_{RFN}}{d} = \frac{4\pi m f^2 d}{eN} \quad (1)$$

Where  $V_{RFN}$  is the amplitude of the RF voltage across the gap,  $f$  is the RF frequency,  $m$  and  $e$  are the mass and the charge of electron, respectively,  $d$  is the gap width and  $N$  is the order of the multipacting ( $N: 1, 3, 5, \dots$ ). The RF magnetic field in the center gap of this resonator is small as compared to the RF electric field. Therefore two side multipacting according to formula (1) is expected in such resonator. The experiment proved that the multipacting occurs at the predicted field.

Most work has been done with copper, Aluminium and stainless steel samples to calibrate the measurement equipment. After each measurement the samples were slightly chemically polished so that a new surface was prepared for the next test. These particular metals were chosen because of their common use in RF systems and their varied secondary emission coefficients  $\delta(E) \geq 1$  at the multipactor electron energy.

Figure 2 shows temporal measurements from the electron probe with respect to the RF power. The power measurement is taken from the RF detectors (RF Diodes) on the incident and reflected power arms of the dual directional coupler. These temporal measurements show evidence of multipacting (MP) electrons when the resonant condition is satisfied and when the RF resonator power is above the threshold value (measured MP threshold values: Al  $\sim 1.5$  W; Cu & S.S  $\sim 3$  W). At the multipactor onset, the reflection coefficient increases proportional to the multipactor current.

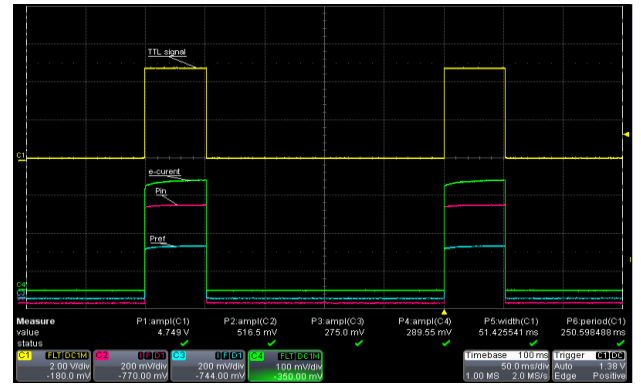


Figure 2: Temporal multipacting current measurement with respect to the RF power: incident power ( $P_{in}$ ) and reflected power ( $P_{ref}$ ) for Cu pair electrodes.

Figure 3 depicts the typical processing behaviour of Al, Cu and Stainless steel samples. The multipacting current is plotted versus time for the RF resonator power set to 14 W i.e. the peak power injected inside the resonator, largely above the onset of multipacting. Typically 14 W of the RF power is ample to reach first order multipacting. The resonator is operated for about 150 minutes (2.5 h)

and as you can see the multipactor disappears and reappears during RF processing. The main characteristics extracted from the experimental results are the typical slow exponential decay time of the multipacting current during RF processing, the long time needed to overcome the multipacting, and the tendency of deconditioning.

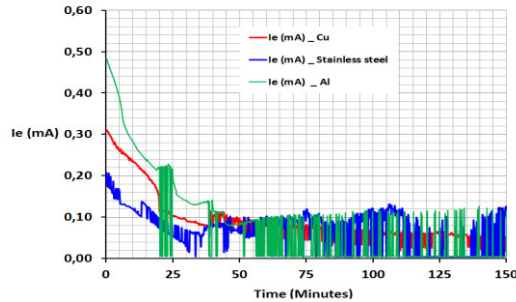


Figure 3: Multipacting current vs. time for 3 different metals.

### *TiN Coating as Multipactor Suppressor*

In this section we compare and contrast the results from the RF power tests of the alumina without a coating, “the non-coated sample” and the Alumina sample with a 20-nm thick TiN coating in order to evaluate a home made sputtered titanium nitride (TiN) thin layers as a Multipactor suppressor. The Alumina was chosen in this experiment because it has a high secondary emission coefficient and is commonly used in the RF vacuum windows.

Figure 4 depicts the view of the resonator with an Alumina (ceramic) sample holder. The alumina slab (1 cm square sample, of height 1mm) is placed in a notch or a nick (square shaped cut) on top of one of the Cu electrodes, and the gap distance is 6 mm. The measured resonant frequency is  $\sim 742$  MHz.

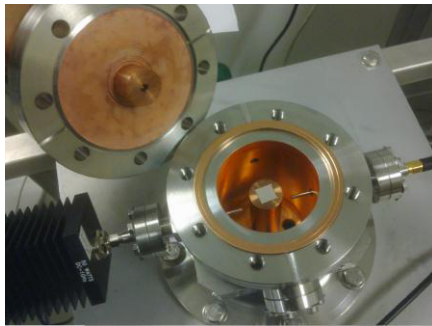


Figure 4: View of the RF coaxial resonator with a ceramic sample holder.

The electron inside the empty gap is accelerated due to the RF electric field. Occasionally the electron collides either with the top surface Cu electrode or with the bottom dielectric layer. Each collision may yield to the emission of the secondary electrons.

TiN thin layers are the most commonly used for multipactor suppression due to their low secondary

emission on the one hand and good stability in RF field on the other.

Figure 5. Shows the efficiency of the TiN coatings, a significant reduction of multipactor current and Time during RF tests were reached. The RF power is set to 4.5 W, above the MP threshold value.

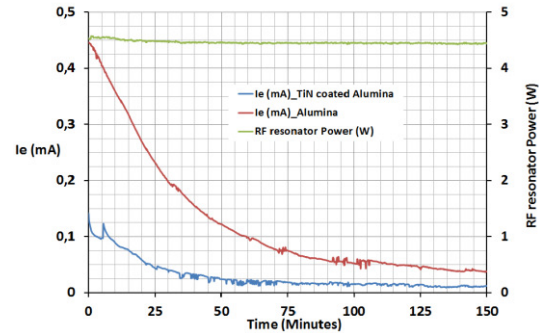


Figure 5: Multipacting current vs. time for 3 different metals.

## CONCLUSIONS

The RF coaxial resonator multipacting experiment provides a test bed for producing and studying two-surface multipactor discharges under various conditions. The apparatus is also used to explore ways to prevent, or extinguish, multipactor by techniques such as TiN coating. Multipactor parameters for different materials, other than Alumina (ceramic), and TiN coating with different thicknesses will be explored.

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